INITIAL ANALYSES OF MULTIPATH FADING MEASUREMENTS FOR VARIOUS GEOGRAPHICAL CONDITIONS IN FRANCE

L. Martin, R.L. Olsen* and T. Tjelta**
CNET, Route de Tregastel, BP 40, 22301 Lannion Cedex, France
* CRC, Department of Communications, Ottawa, Canada K2H 8S2
** Televerkets Forskningsinstitutt, Pb 83, 2007 Kjeller, Norway

Introduction. With the introduction of digital radio into national telephone networks, a new need has arisen for a good method of predicting the outage time due to fading in variable clear-air conditions. A particular difficulty is the necessity to take into account the distortion due to selectivity of the fading in the digital radio band. The complexity of making selectivity measurements on a large number of hops suggests the search for a good understanding of this phenomenon on a few hops only [1,2]. Under the assumption that the single frequency fading distribution can be used as part of a prediction method taking into account the distortion due to selectivity (see, for example, [3]) for various geographical conditions, such single frequency data are now being collected on a large number of hops in the French microwave network.

Few countries have carried out such large scale measurements of fade depth statistics at a single frequency. In Japan [4,5] and in the U.S.A. [6], the outcomes of early measurement programs were prediction methods based on the path length, the frequency, and an approximate factor defining the terrain characteristics. Later in the U.S.A. [7] and in Great Britain [8], an additional term taking into account the terrain profile roughness was introduced. The current measurement program in France includes the simultaneous measurment of meteorological statistics with the propagation statistics, with the aim of better defining the climatic variability. In this paper, a brief description of this experiment and the results of the first analysis are given.

Experiment description. At this stage of the experiment, 20 links located in various geographic and climatic regions of France are being monitored, most of them analog. It is expected that about four more links will be added in the future. The choice of links was based in large part on the assumption that the fade depths statistics depend primarily on the path length and terrain roughness. The range of path lengths is from 28 to 95 km, and the range of roughnesses from 3 to 127 mrad. The frequencies cover the 4 to 15 GHz range, with the greatest number in the vicinity of 6.5 GHz.

Each monitoring station realized for this experiment collects the fade depth statistics for two adjacent hops at the common nodal point. These statistics are obtained for three fade depths large enough to concern only the tail of the distributions. Meteorological data are also measured at two points. Atmospheric pressure, dry and wet bulb temperatures and rain intensity are measured at the bottom of the radiolink tower, dry and wet bulb temperatures, wind speed and wind direction, at the top. A single set of these data is saved for each four hour period. However, refractivity gradients are calculated every three minutes from these measurements and statistics for five gradient thresholds are then obtained for each four-hour interval. Statistics on rain intensity for a one minute integration time are also recorded. Later in the program, measurements of bit error rate and in-band amplitude difference will be added for several of the 11 GHz digital links monitored. All the statistics and the four-hourly instantaneous measurements are transmitted to a central location via the ARGOS service of two U.S. environmental satellites.

A duration of two or three years is planned for this experiment which began in June 1983. In the results of the first data analysis presented in the following section, only nine ARGOS links have been included. However, sufficient data were measured in each case to determine the worst-month fade depth during a one-year period. To supplement these results for the initial analysis, worst-month statistics existing for 10 other links in France have also been included. For the few links in this additional group where more than one year of data was available, the fade depth distribution for the average worst month was used.

Data analysis. The principal analysis is directed towards finding a prediction equation of approximate general form

$$P = K\, F_1(d)\, F_2(f)\, F_3(S)\, F_4(h)\, F_5(\varepsilon)\, F_6(\theta)\, 10^{-A/10} \qquad (1)$$

relating the probability P of exceeding a fade depth A in the deep-fading range of the worst-month distribution described by the Rayleigh slope of 10dB/decade. Here, d is the path length, f the frequency, S a terrain roughness statistic, h the path clearance, ε the path inclination, and θ the geometric mean beamwidth of the antennas. It is assumed that K is a general climatic factor characteristic of a large region rather than the local region of the path.

Since the application of (1) depends on the assumption of a Rayleigh slope, it is important to evaluate this assumption. A simple calculation of the average slope for the initial sample of 19 paths, based on the 0.1% and 0.01% levels of each distribution, gives a value of 9.5 dB ±1.1 dB, where the estimated 95% confidence limits are based on twice the estimated standard error. Thus, for this sample of propagation paths, the assumption of the 10 dB/decade slope seems appropriate.

Because of the small size of the existing data set, the initial analysis has so far concentrated on the variables d, S, and f. In particular, it is assumed that

$$P = K\, d^{\alpha} f^{\beta} S^{\gamma}\, 10^{-A/A_s} \qquad (2)$$

where the terrain roughness S is defined as the r.m.s value of terrain slopes in milliradians between points separated by 1 km along the path, but excluding the first and last complete 1 km intervals [8], and A_s is the distribution slope in dB/decade. This power-law form and the corresponding relation

$$A = G + a\log(d) + b\log(f) + c\log(S) - A_s\log(P) \qquad (3)$$

with A_s=10, are known to be approximately valid for the U.K. [8]. In fact, the frequency term is quite weak in this and most previous analyses based on (2) or similar power-law forms [6,8]. Shown in Fig. 1, for example, are scatter plots based on the 19-sample data set illustrating the dependence of P(0.1%) on only d and S. The line showing the d dependence was determined by simple linear regression, then the line showing the S dependence, in the same way after normalizing for d. The points about the fit in S are normalized for a distance of 48 km.

Although Fig. 1 graphically illustrates the importance of including path length and terrain roughness (or a corresponding variable) in any prediction method, it is difficult to accurately determine the dependence of P on each variable separately. Therefore the more genèral approach of multiple regression [9] is being employed. It has previously been applied by Crombie [10] for fitting power-law equations to worst-month data at a constant fade level of 20 dB. As can be seen readily from eqn. (3), this approach can be generalized to include the probability P as an independent variable. In this generalized approach the average distribution slope A_S can be determined in the regression analysis, and the distribution probabilities can be chosen to ensure that they are in the tail.

This general approach has been applied to fit eqn. (3) to the initial 19-path sample, with the assumption that G is a constant for all paths. For convenience in this first analysis, measured distribution fade depths exceeded for 0.1% and 0.01% of the time were employed. In most cases these fade levels were in the distribution tails. The resulting equation (3) has coefficients

$$a=38.4\pm14.8,\ b=3.9\pm8.6,\ c=-8.7\pm4.3,\ A_S=9.5\pm2.8,\ G=-63.4\pm29.6$$

where the estimated 95% confidence limits are based on twice the values of the estimated standard deviations of these coefficients. The corresponding coefficient of multiple correlation is R=0.85 and the estimated standard deviation of the predicted A values from the measured values is 4.3 dB.

Because of the small amount of data so far obtained, this regression fit cannot be considered a definitive one. The necessity of the frequency term is particularly uncertain, and the accuracies of the coefficients a, c, and G, although significant, are not as high as desirable. However, the results are encouraging and illustrative of the general approach being employed in the analysis. Additionally, it might be noted that the value of the slope A_S derived from the multiple regression is equal to the mean slope calculated directly.

Although this fit was carried out independently of any knowledge of the meteorological information for the paths, eventually it is hoped to use the two-point meteorological statistics to determine a more accurate relation. The observed relationship between the monthly probability of exceeding a fade depth of 20 dB and a refractivity gradient of -157 N units/km, shown in Fig. 2 for two adjacent paths of approximately equal lengths, is particularly encouraging. The value of -157 N units/km was chosen because it is the critical value for the formation of propagation ducts associated with multipath propagation. However, smaller values could equally well be used because of their high correlation with this value and because the two-point nature of the measurement necessarily involves some smoothing.

The two lines in Fig. 2 were based on a simple regression fit to the data points for each link. The difference in the slopes of each line is not significant for the number of points included in the fits. The difference in the intercepts is significant and is believed to be due to the use of a single two-point gradient statistic for both paths and the fact that the path inclinations, average clearances, etc., are not identical.

Discussion. The accumulation of more data for each link and the addition of data for new links is expected to increase the accuracy of the results and allow the dependence on some other variables to be determined. Initial analysis of data from 45 links in both France and Great Britain is encouraging. This analysis, for example, shows the frequency term in equation (2) to be significant although weak. An other analysis on a subset of the data (see also [10]) shows path clearance and antenna beamwidths to be important. The necessity for a variable geographical/climatic factor (i.e., K in eqn (2) or G in eqn. (3)) as determined by Doble [8], has been confirmed, at least in the absence of a measured meteorological variable in equation (2). Other analyses are in progress to determine whether more physically appropriate functions for certain variables (in particular the terrain roughness, which in (2) gives $P \to \infty$ as $S \to 0$) can be found.

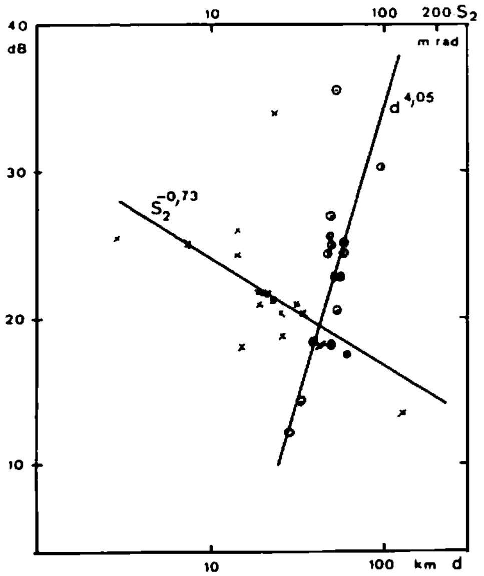

Fig. 1. Scatter diagrams of A(0.1%) versus path length d and terrain roughness S.

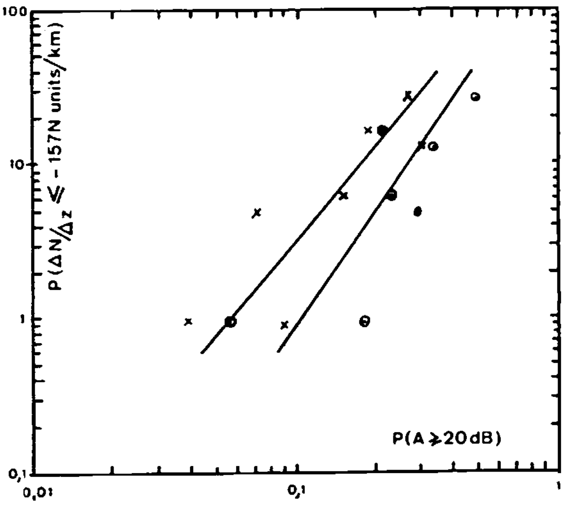

Fig. 2. Scatter plot of monthly percentages P(A 20dB) versus P(ΔN/ΔZ -157 N units/km) for two adjacent links near Orleans (summer and autumn months).
o link with d=48km, S=3mrad,
× link with d=46.5km, S=6mrad.

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